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CONTRIBUTION TO THE PROBLEM OF THE MANUFACTURE OF SPONGE IRON BY MEANS OF NATURAL GAS IN THE SHAFT FURNACE

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CONTRIBUTION TO THE PROBLEM OF THE MANUFACTURE OF SPONGE IRON BY MEANS OF NATURAL GAS IN THE SHAFT FURNACE

by

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The production of iron and steel directly from ore, i.e. without the use of the blast furnace, is an old metallurgical problem. Also in the course of the "Technical Age" there have been time and again experiments, since 1843, to produce iron and steel from ore direct. In 1942, R. Durrer[1] still mentioned 138 methods dealing with the direct production of iron and steel. Now about 30 processes are still concerned with this old problem, partly in laboratories, partly in pilot or in full-scale plants.[2] Of these 30 methods about 10 processes use gas as reducing agent. With part of those methods the gas is produced from coal, coke or oil. Some few processes have been dealing with the use of natural gas as reducing agent[3], and this is the topic of the following considerations.

Preparation of gas

In its original form natural gas, chiefly consisting of methane, is not quite suitable for reducing iron oxide. Therefore, in all cases it is necessary to reform the natural gas - prior to its use as reducing agent - to gas mixtures suitable for reduction purposes and rich in hydrogen. Reforming can be carried through with the aid of oxygen or steam. It takes the form of the following reaction:

$$CH_4 + 1/2\ O_2 = CO + 2\ H_2$$

$$CH_4 + H_2O = CO + 3\ H_2$$

The reformed gas always retains a certain content of carbon dioxide and steam interfering with the reducing process. A good reducing gas for metallurgical purposes must meet the following requirements:

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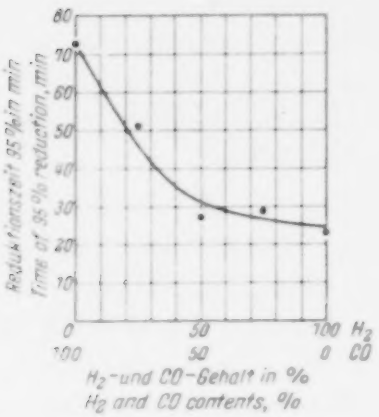
1) Metallurgie des Eisens - R.Durrer, Verlag Chemie GmbH, Berlin
2) Verfahren der direkten Reduktion von Eisenerzen, European Coal and Steel Community, Bibliography 1960
3) L.von Bogdandy, Stahl und Eisen 82 (1962), Page 869

Content of carbon dioxide and steam max. 2 %, methane max. 5 %, nitrogen max. 10 %. These requirements have to be complied with by a suitable control of the reforming process and, if necessary, by a following purification of the gas.

It is known that the reducing reaction is fundamentally different with carbon monoxide and hydrogen. Hydrogen-rich gases are utilized better at higher reduction temperatures. As to the reduction by carbon monoxide, however, lower reduction temperatures appear more favourable. Furthermore, it can be noted that hydrogen-rich gases reduce considerably quicker than carbon monoxide does (see Fig. 1).



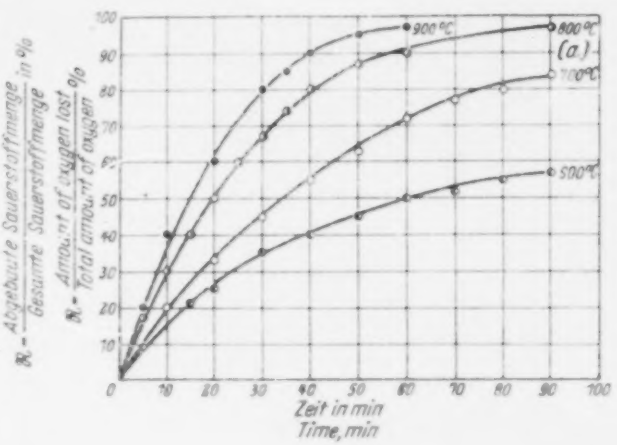
Time of reduction (degree of reduction: 95 %) as a function of hydrogen and carbon monoxide content of gas

Fig. 1

It is clearly to be seen that increasing temperatures result in a shorter time of reduction. However, an upper limit for the temperature is given by the softening of the ore. It lies at

The rate of reduction of pure hydrogen is three times as high as that of pure CO.

Finally the degree of reduction depends, to a great extent, on time of reduction and reduction temperature, as shown in Fig. 2 for the reduction with H_2.



Degree of reduction is a function of time and temperature. Isothermal reduction of iron(III)-oxide pellets (30 mm dia.) by hydrogen

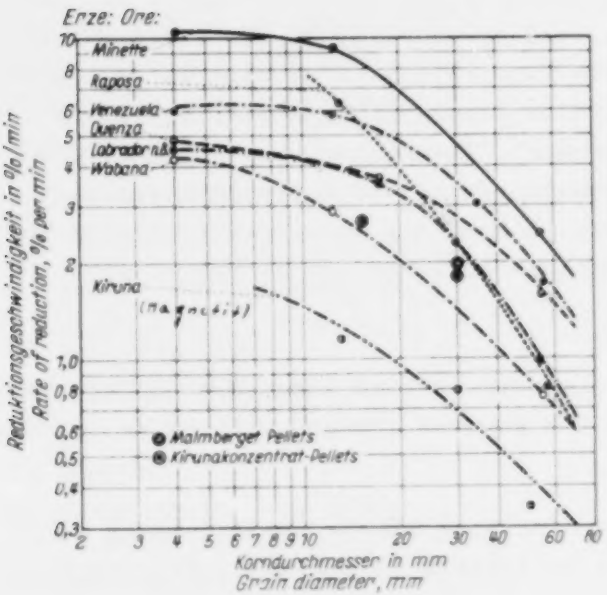
Fig. 2

about 1000 to 1100° C. An increase of the pressure will not result in any considerable acceleration of reduction so that it might hardly be necessary to revert to this means. This will substantially simplify the construction of the corresponding reduction furnaces.

The reduction process is based on the following formula:

$$Fe_2O_3 + 3\ H_2 = 2\ Fe + 3\ H_2O$$
$$+ 195\ kcal/kg\ Fe$$

$$Fe_2O_3 + 3\ CO = 2\ Fe + 3\ CO_2$$
$$- 69\ kcal/kg\ Fe$$



Relationship between lump size and rate of reduction of ores

Fig. 3

The rate of reduction is influenced, naturally, by the selected lump size of the ore input. The connection between lump size and rate of reduction is shown in Fig. 3.

Furthermore, it is to be noted that reduction of hematites is easier than reduction of magnetites. The max. lump size for the ore to be reduced lies between a grain diameter of 10 and 20 mm.

Reduction Process

Among the gas reducing processes the "fluidized-bed processes" occupy a special position.[1] According to these processes fine ores ground to the form of powder are reduced in

[1] J.Willems a. G.Quade, Stahleisen (1959), page 1058

a state of suspension in the gas. By this method optimum times of reduction are reached, it is true, but, on the other hand, its use in industrial scale is limited by the complicated mechanism derived from the chemical industry. For greater production units standing in competition with the "orthodox" manufacturing processes for iron and steel as usual, so far, chiefly such processes are coming into question using methods and types of furnaces approved in metallurgy as, for instance, rotary furnaces or shaft furnaces. The comments following below are limited to the description of the shaft-furnace process, the full-scale utilization of which in metallurgical works is approaching realization.

In practical metallurgy the shaft furnace represents the reaction aggregate par excellence. Blast furnace, cupola furnace, and lime-burning kiln are well-known examples for its application. The advantages of this furnace are to be seen in the automatical use of the counterflow principle, its easy operation (without motion of the furnace), its optimum heat balance and its optimum gas passage leading to an optimum output per unit of volume of reaction space. Therefore, it suggested itself to use the shaft furnace principle also for the method of direct reduction.

When reduction of the iron ore is carried through with natural gas in the shaft furnace, the process scheme[1] will be as follows (see Fig. 4).

One of the two gas reformer furnaces always is in working position whilst the other is in heating-up position. The ore is charged at the shaft furnace top, as usual, and travels - with progressive reduction - towards the lower part of the furnace. The hot reducing gas is fed into the shaft at the bottom and flows through the ore according to the counterflow principle. The reducing gas received at the top is partly used for heating the gas reformer furnaces and partly fed back (as circulating gas) into the gas reforming system.

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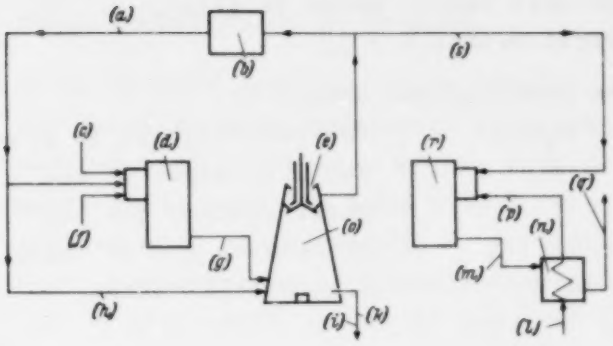
[1] L.von Bogdandy, Stahl und Eisen 82 (1962), Page 869

Fig. 4



Flow diagram of an industrial reduction plant with production of reducing gas from natural gas and oxygen.

(a) recovered top gas
(b) condensation of reaction water vapour to 35°C (dew-point) and compression
(c) methane (calorific value = 8580 kcal/Nm^3)
(d) reformer furnace I
(e) input: ore (Fe_2O_3)
(f) oxygen
(g) reducing gas (33 % CO, 67 % H_2; 1000°C)
(h) cooling gas
(i) sponge iron (97 % Fe, 2 % C; 300° C)
(k) to cooling drum
(l) blast (pressure 300 mm w.g.)
(m) waste gas (1000°C)
(n) recuperator
(o) reduction shaft
(p) hot blast (600°C)

When lump ore is used, the shape of the ore lump is maintained when it passes through the furnace and it is discharged as sponge iron of the same lump size. The same goes for the use of pellets which are very suitable for a reduction with natural gas in the shaft furnace. In this process the best results are reached with pellets having a diameter of 20 to 30 mm.

There are three different plants which are working at present, according to the shaft-furnace principle:

(q) waste gas (500°C)
(r) reformer furnace II
(s) top gas for combustion (300°C; calorific value = 2140 kcal/Nm3)

(1) The plant of M. Wiberg, Soederfors, Sweden,
largest production unit built: about 70 t/day,
shaft diameter/height ratio: 1 : 5;

composition of the reducing gas used:

H_2 %	CO %	CO_2 %	H_2O %	
21.1	74.4	3.2	1.2	The reducing gas is produced by means of coal gasification; the use of natural gas is taken into consideration.

(2) Plant of Finsider, Italy,
production unit: 70 t/day,
shaft diameter/height ratio: 1 : 5;

composition of the reducing gas used:

H_2 %	CO %	CO_2 %	H_2O %	
27	63	5	5	The reducing gas is produced from coal. It is intended to add methane.

(3) Purofer plant of Huettenwerk Oberhausen, Germany,
production unit: about 3 t/day,
shaft diameter/height ratio: 1 : 4;

composition of the reducing gas used:

H_2 %	CO %	CH_4 %	CO_2 %	
63.1	25.4	4.7	1.7	The reducing gas is produced by catalytically reforming natural gas.

The a/m Wiberg plants are satisfactorily working, in continuous service, for about 30 years. They produce sponge iron which is used as scrap in the charge of the steelworks.

The Finsider plant will be put into operation at the end of 1962. It serves as mere pilot plant for the member countries of the European Coal and Steel Community.

The Purofer plant in Oberhausen is manufacturing in continuous operation, for 2 years, about 3 t per day of sponge iron which

is then worked to iron powder for powder metallurgy. The relatively low production rate is due to the limited market for iron powder. A greater plant with a daily output of 50 t is under construction at present.

As to be seen from the above details, the reduction conditions are becoming more favourable with a higher H_2 portion in the reducing gas and with a higher reduction temperature. That means that, with the same output, the shaft volume becomes smaller with an increasing H_2 portion in the reducing gas. Thus, for instance, a furnace operated with H_2 would need only 1/3 of that shaft volume as required by a furnace using CO reduction as the reduction rate of H_2 is three times greater than that of CO (see Fig. 1). This is why, at present, the Purofer furnace requires the specifically smallest volume and the smallest height of shaft.

An increase of the output of the shaft furnaces working with natural gas, beyond the a/m rate, to production units of, for instance, 300 t per day of sponge iron per unit, obviously will not meet with any considerable difficulties as shaft furnaces with a discharge of solid material of these dimensions are known and are used in practice since long already (example: lime-burning kilns).

Deliberations concerning profitability

To judge the profitability of the gas reduction process as described above, it is interesting to ascertain, as comparison, the costs of pig iron arising when a) the traditional blast furnace process is used and b) ore reduction is carried through in the shaft furnace by means of natural gas and then synthetic pig iron is produced from the sponge iron with the aid of a suitable equipment for subsequent remelting. It seems to be advisable to select the pig iron manufacture as standard of comparison as pig iron is the usual raw material for the further iron and steel production in development countries with plentiful supplies of ore and, in most cases, a shortage of scrap

and which, therefore, is particularly suitable for comparison purposes.

The capital costs for a complete gas reduction plant, incl. remelting equipment, will show a minor difference only as compared to the costs for a blast furnace plant of the same size. Anyhow, they will be lower, due to the simpler and smaller shaft and to some other simplifications as compared to the blast-furnace process. But this reduction of the capital costs is neither decisive nor does it greatly influence the production costs. Likewise the fact that less manpower is needed will be relevant. Predominantly decisive and of first importance for all considerations in connection with the new process will be only and alone the fuel costs. In this respect the development countries disposing of natural gas have an essential advantage over the old industrial centers, e.g. in Europe. In South America, for instance, coke is very expensive as most of it has to be produced from imported coal. On the other hand, natural gas costs less than 0.5 c.(US$)/standard cu.meter. If the consumption of natural gas is charged with that price - the upper limit of the prices known to us - in the cost accounting, the fuel costs will amount to about $ 2.50 per ton of pig iron in such a combined sponge iron - pig iron plant. For a blast furnace located in South America the fuel costs would be about $ 16.50 per ton of pig iron. This disadvantage is decisive and could hadrdly be overtaken by the traditional blast furnace process - in spite of many improvements.

The a/m comments clearly show the great importance of the process, as described, for the future extension of iron industry in such development countries having gas and oil supplies at their disposal. For those countries, which often possess simultaneously cheaply mined ore reserves but, in most cases, are short of coking coal, the process of direct reduction of the indigenous iron ores by means of natural gas in the shaft furnace may become the decisive turning point for starting an own iron industry competitive on the world market.

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